AN ANALYSIS OF THE ERICSSON HOT AIR ENGINE

CLINTON REUEL STEWART
EUGENE WILSON YEARSLEY

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An Analysis of the Ericsson Hot Air Engine.

Clinton Reuel Stewart.
Eugene Wilson Yeasley '97.

Stewart & Yearsley '97

A Ericsson Engine.

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Analysis

of the

Pressman Steel Engine.

4 June '48. Sev. St. Louis. S.C.R.

Analysis of the Ericsson Hot Air Engine.

The object of the test was to determine the various efficiencies of the Ericsson Hot Air Engine used for pumping water. The engine tested was an 5" x 4," rated by five groups of Bunsen burners each consisting of three jets. The gas used was ordinary illuminating gas taken from the city mains. The engine was not new and had been in use for several years.

Two runs of four hours each were made. The first at a low head, and the second at a head a little below the engine's limit. The engine was found to be more efficient at a low head. The test under a low head more

nearly approached the conditions for which the engine was designed.

The pressure pumped against was obtained by throttling the discharge, and was measured on a Bourdon Gauge. The pressure between strokes was kept approximately steady by means of air chamber on discharge pipe. The fluctuation of gauge was prevented by means of a throttling valve between pipe and gauge.

The water was pumped from the lower tank shown into the two upper ones alternately from which it was discharged into the lower tank again. The water pumped into upper tanks was weighed upon the two fairbank's Platform

Scales. The height from the level of water in tower tank to centre of gauge was also measured.

The gas burned was measured through a commercial gas meter. Reading was taken at beginning and end of run. The pressure of the gas was measured on a Bristol Recording Gauge. The temperature of gas in meter was read from a thermometer placed beside meter. The pressure of atmosphere was obtained from a Queen Fortin barometer in the Laboratory. The mean of four complete analyses, made in the Chemical Laboratory, of city gas was taken and from this the heat value of gas burned was derived. The completeness of combustion was determined by analysis with Elliot & Barakes

of products of combustion.

The temperature at the top and bottom of cylinder was needed to determine the thermodynamic efficiency of the engine. It was impossible to calculate from the card since the weight of air within the cylinder was unknown and constantly changing. They were determined by means of the change in resistance of a coil of iron wire. The coil for the bottom temperature was of #40 wire, wound on mica and insulated from walls of cylinder by means of asbestos paper. The ends of the wire were wrapped in asbestos & apart, then wound with copper wire, and led up the side of the cylinder and out through the

hole tapped for the indicator. The insulated leads are continued on out to a T and up vertically through a long nipple. The vertical pipe was poured full of Plaster of Paris to prevent air escaping, and other portion of T closed with indicator valve. The space left between the cylinder walls and brass piston was so small (less than 1/8 inches) that it was found impossible to find temperature during the actual run since the large amount of extra friction of the piston on the leads would vitiate the results and also cause the insulation to quickly wear through and break the wires. The coil and iron leads contained about thirteen feet of wire.

In the measurement of the resistance of coil a Queen d'Arsonval Galvanometer #3 and Queen Bridge #41 was used.

Resistance of leads from coil to Bridge box

Ratio of arms.	Ohms from box.	Resistance.
1000-1	155.5	.1555
1000-1	155.5	.1555

Twenty-one inches of iron leads of coil outside of cylinder or twenty-two inches of wire gave at 68° Fah.

Ratio of arms	Ohms from box	Resistance.
100-1	306	3.06

This corrected to 55° Fahr (by substitution in equation of curve afterwards determined) gives a resistance of 2.937 ω.

Resistance of coil and leads at 55° Fahr.

Ratio of arms.	Ohms from box.	Resistance
1000-1	14465.5	14.4655
1000-1	14475.0	14.4750
1000-1	14470.0	14.4700
1000-1	14486.5	14.4865

Mean resistance = 14.474 Ohms.

The bottom of cylinder was raised to about the same heat (cherry red) as during run and same amount of gas burned (47 cu. ft. per hr.).

Resistance of hot coil and leads:-

Ratio of arms.	Ohms from box.	Resistance.	Rev. per min.
100-1	5530	55.30	[illegible]
100-1	5670	56.70	30
100-1	5640	56.40	32
100-1	5640	56.40	31
100-1	5660	56.60	40
100-1	5610	56.10	46
100-1	5550	55.50	46
100-1	5606	56.06	42

100 - 1	5600	56.00	55
100 - 1	5566	55.66	56
100 -	5810	58.10	36

Mean resistance = 56.244 Ohms.

The resistance and consequently the temperature thus appears to change with the number of revolutions and in the reverse direction, i.e. the greater the speed the less the temperature since more heat is transferred, but not by any means in proportion showing that there was a great excess of heat to be drawn from without, and would serve to indicate that if the engine could be run at an increased speed much more work could be gotten out of it provided the friction was not corresponding ly increased.

The coil was calibrated and

the expression for the temperature co-efficient of change of resistance found by putting the coil inside a short section (about 15" long) of 6" mug nesia tube covering, filling up the ends with Plaster of Paris through which small openings were left for leads and thermometer. The whole was mounted on a tripod and heated with several Bunsen burners. The coil was suspended off the bottom; and a thermometer divided every 2° up to 600° Fahr., was in along side of and touching it.

Readings were made as the temperature rose and also after burners were removed and calorimeter and contents cooled off. Certain resistances were taken out of the box and then as the bridge came in balance the corresponding

temperatures read. The temperatures were thus taken up and down for the same resistance of coil and so the difference in the rate of cooling of the coil and thermometer could in a measure be eliminated.

The means of the temperatures for the various resistances were obtained and plotted as shown in the curve.

The same electrical instruments were used in the calibration as previously.

The resistance of the German Silver leads was found to be

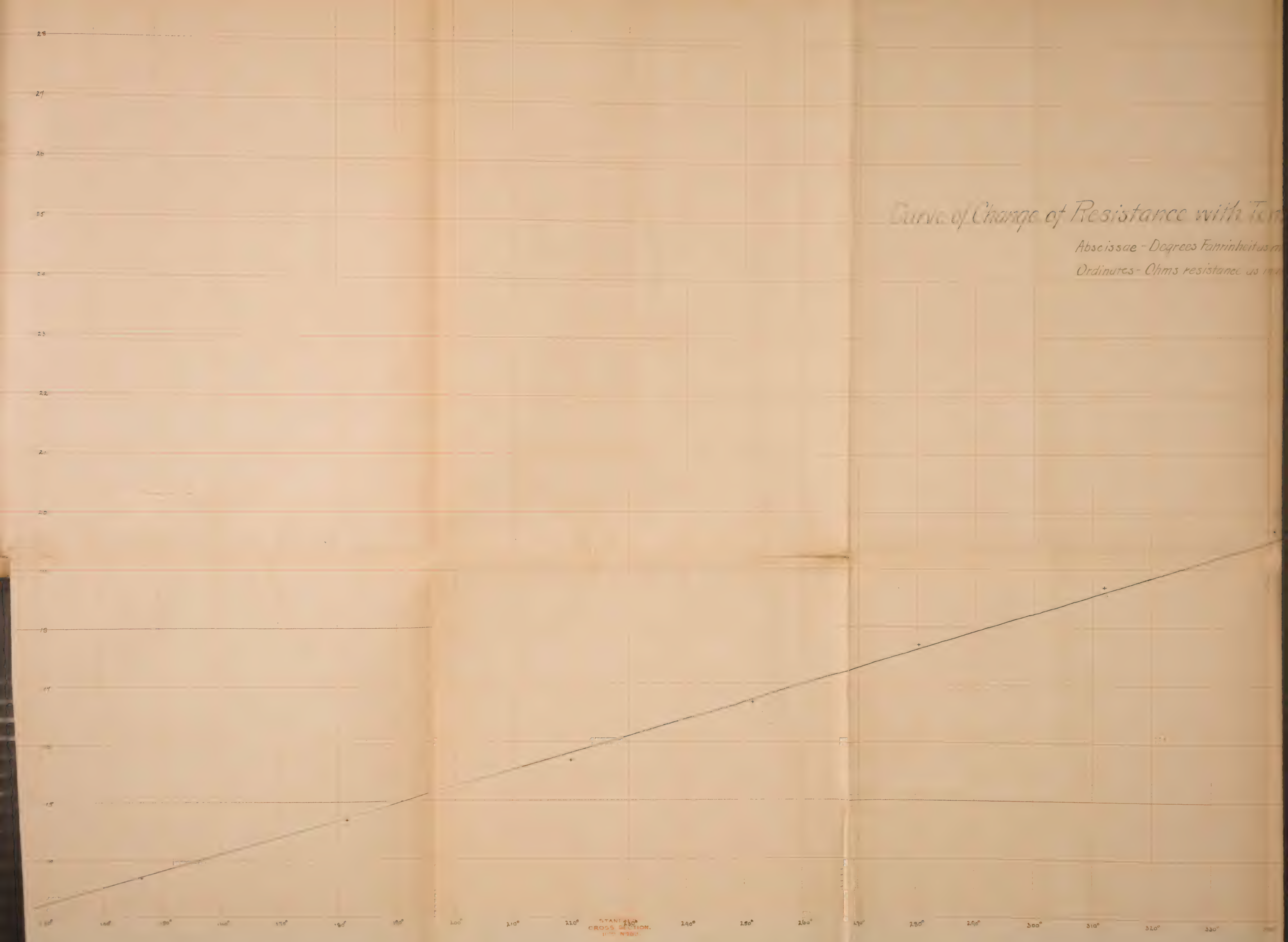
Ratio of arms	Ohms from box.	Resistance.
1000-1	3320	3.320

This amount was subtracted from the varying resistance of the coil in the calibration. The following are the results of the

Curve of Change of Resistance with Tem

Abscissae - Degrees Fahrinheit as m

Ordinates - Ohms resistance as m



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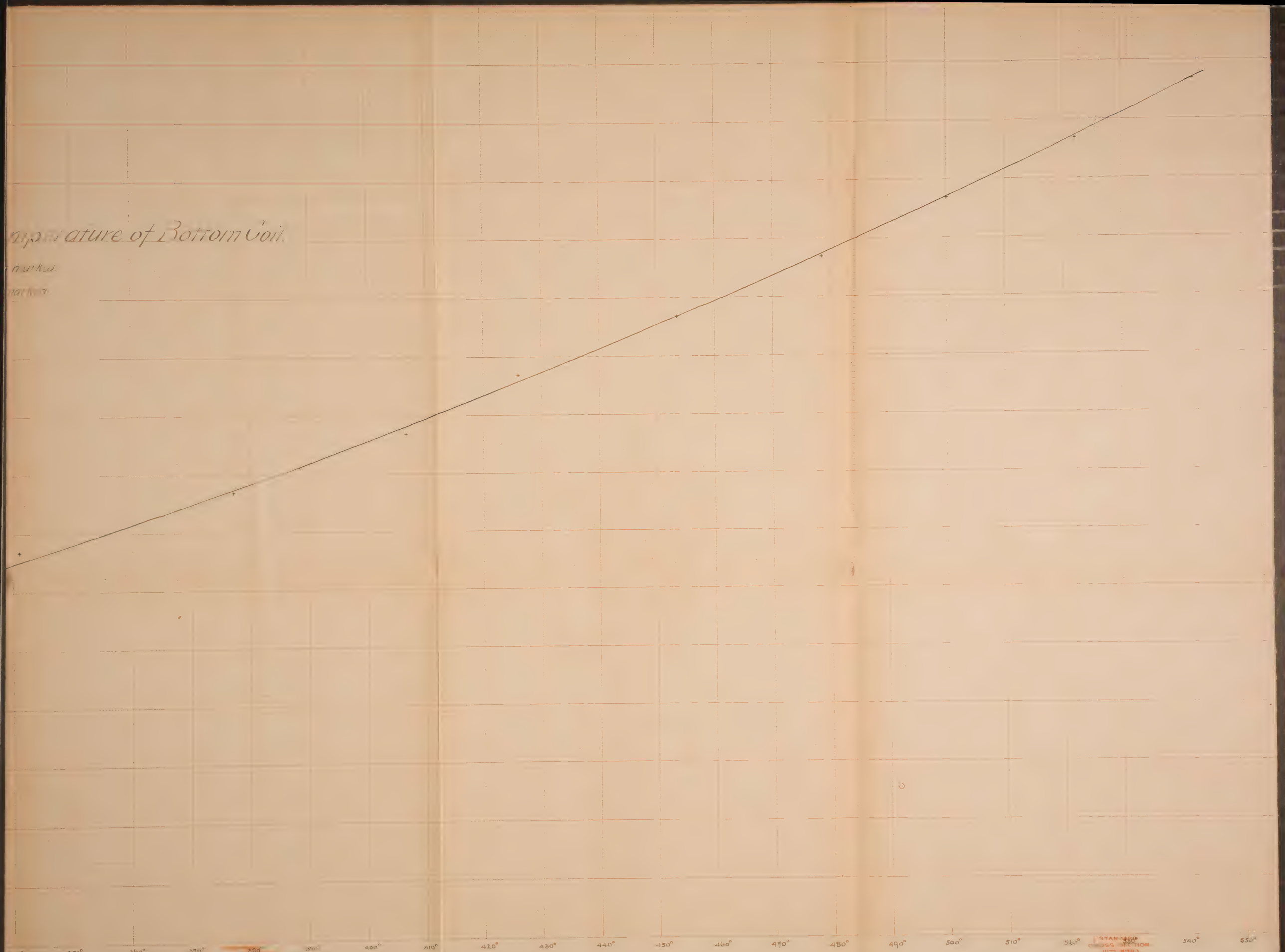

ature of Bottom Coil.
marked.
350°
360°
370°
380°
410°
420°
430°
440°
450°
460°
470°
480°
490°
500°
510°
520°
530°
540°
550°

calibrations:-

Temp. degrees Fahrinheit Up	Down	Up	Down	Mean	Ratio arms	Ohms from box.	Res.	Resistance less leads
139	154			146	100-1	1700	17	13.68
174	189	188	190	185	100-1	1800	18	14.68
207	222	226	225	220	100-1	1900	19	15.68
242	253	255	256	251	100-1	2000	20	16.68
275	286			280	100-1	2100	21	17.68
306	318			312	100-1	2200	22	18.68
334	348			341	100-1	2300	23	19.68
360	377			368	100-1	2400	24	20.68
398	409	390	404	400	100-1	2500	25	21.68
418	431	423	432	426	100-1	2600	26	22.68
450	458	444	454	453	100-1	2700	27	23.68
474	483	468	480	476	100-1	2800	28	24.68
493	507			500	100-1	2900	29	25.68
521	523			522	100-1	3000	30	26.68

The curve is apparently of the form of a parabola $y^2 = -4ax$, transforming the co-ordinates to the new axis given $X = KY - LY^2 - M$ where

X - temperature and Y - resistance

The constants in the equation were found by the Method of Least Squares. Those temperatures which were a mean of four readings were given a weight of two, while those which were the mean of two readings only a weight of one. The following are the observation equations with their weights:-

Wts.	Observation Equations.
1	$522 = 26.68K - 711.5L - M$
1	$500 = 25.68K - 659.5L - M$
2	$476 = 24.68K - 609.1L - M$
2	$453 = 23.68K - 560.7L - M$
2	$426 = 22.68K - 514.4L - M$
2	$400 = 21.68K - 470.0L - M$
1	$368 = 20.68K - 427.7L - M$
1	$341 = 19.68K - 387.3L - M$
1	$312 = 18.68K - 348.9L - M$
1	$280 = 17.68K - 312.6L - M$

2	251 = 16.68K - 278.2 L - M
2	220 = 15.68K - 245.8 L - M
2	185 = 14.68K - 215.5 L - M
1	146 = 13.68K - 187.1 L - M

giving the normal equations for L, K and M,

$-3444210.8 = -190649.7K + 3389840.3L + 8823.5M$

$15624.5.4 = +8823.5K - 190649.7L - 422.28M$

$-7293 = -422.28K + 8823.5L + 21M$

solving for the three variables gives $K = 28.804$ $L = .00249$ $M = 232.98$ or the equation is

$X = 28.804Y + .00249Y^2 - 232.98$

At 55° fahr. the coil, leads, etc, measured 14.4865 Ohms. This less the copper leads (.1355 w) and corrected resistance of iron leads (2.937) gives 11.378 w as the resistance of the wire within the cylinder. At 55° fahr. the portion calibrated would

have measured 9.99 ω. When heated the total resistance was 56.244 ω of the portion within the cylinder measured 53.148ω, subtracting the leads.

Let X_1 = temp. at bottom of cylinder.

$$X_1 = 28.804 \times \frac{9.99}{11.378} \times 53.148 + .00249 \times \frac{9.99}{11.378} \times 53.148 - 232.93$$

$$= 1116^\circ \text{ Fahr.}$$

The temperature at the top of the cylinder was found by another coil of #32 iron wire wound on a board, insulated with asbestos paper, and fastened to the bottom of the motor piston. One of the bolts clamping the retaining ring of the cup leather was removed and the leads passed through the hole being insulated with asbestos. The coil contained about eighty feet of wire. The measurement of

the resistance was made with the same instruments. The gas and appearance of the bottom of cylinder was regulated to same condition as run.

At temperature of 69° Fahr with ratio of 100-1, coil and leads measured 36.845 ω. The resistance of copper leads = .155 ω. The resistance of iron without the cylinder .732 ω at 69° Fahr.

The resistance when hot was,

Ratio arms	Ohms from box	Resistance	Condition of bottom of cylinder.	Revolutions per minute.
100-1	4657	46.57	Dark red	60
100-1	4650	46.50	" "	56
100-1	4657	46.57	" "	56
100-1	4709	47.09	Cherry Red	64
100-1	4754	47.54	" "	72
100-1	4750	47.50	" "	56
100-1	4833	48.33	Bright red	62
100-1	4853	48.53	" "	66

Temp. of feed water 76° 77°. Outflow about 78°. The mean resistance was 47.241 ω. The resistance within the cylinder was 46.354 ω. The change in speed made no apparent difference in the temperature at the top.

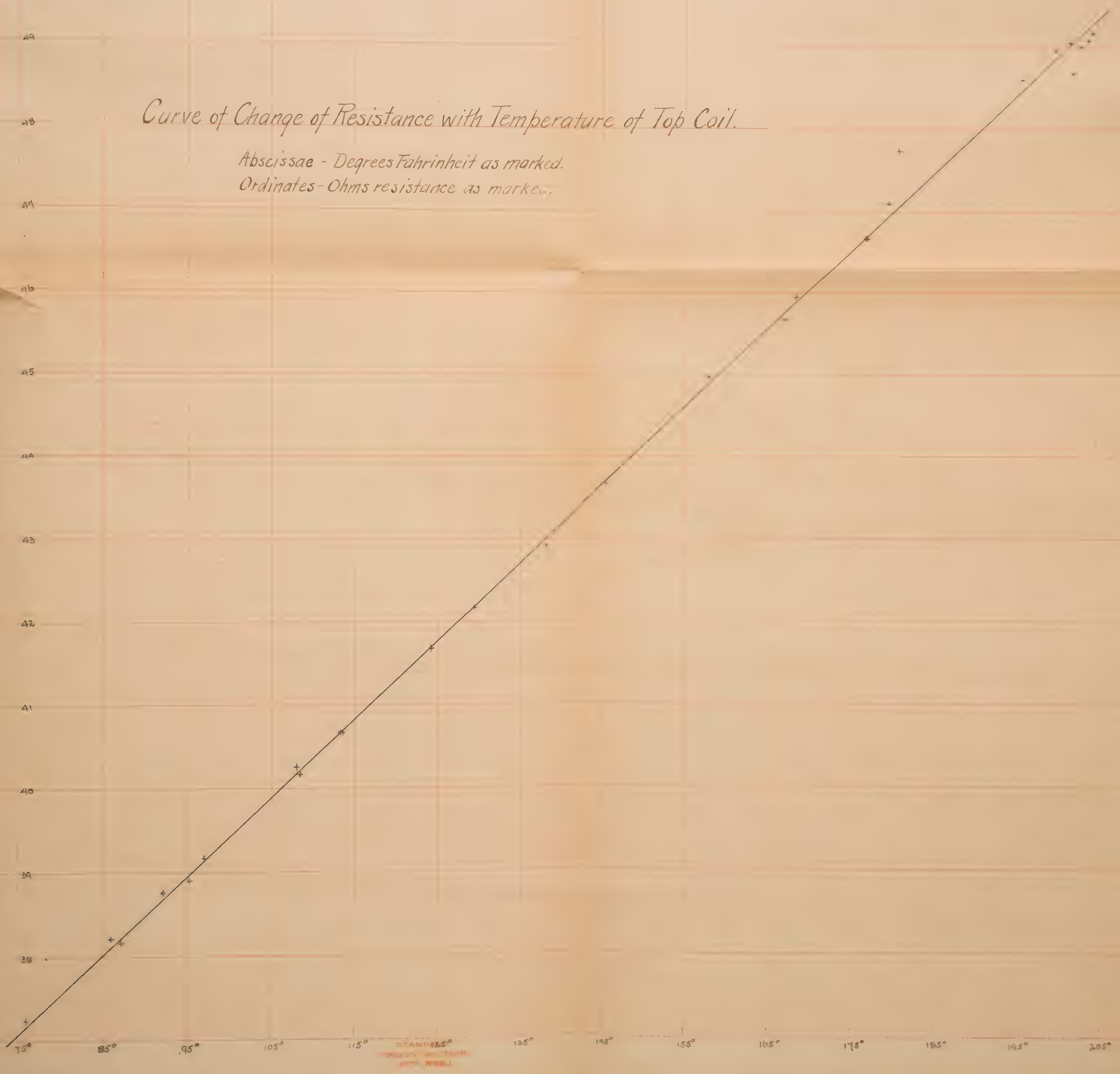
The wire being of different make from other coil was calibrated in an oil calorimeter. The resistance was measured on Queen Bridge #39 and Willyoung d'Arsonval galvanometer used. The temp. was read on a Queen thermometer reading every 2° up to 400° Fahr.

The leads used were of German Silver same as in previous calibration. Their resistance was 3.320 ω. The calibration readings were :—

Ratio of arms	Ohms from box	Resistance	Corrected resistance.	Temperature degrees Fahr.
1000-10	4054	40.54	37.25	76.0
1000-10	4155	41.55	38.23	86.0
1000-10	4350	43.50	40.18	108.4
1000-10	4400	44.00	40.68	113.2
1000-10	4650	46.50	43.18	156.0
1000-10	5200	52.00	48.68	202.0
1000-10	5000	50.00	46.68	177.0
1000-10	4900	49.00	44.68	167.3
1000-10	5234	52.34	49.02	203.0
1000-10	5241	52.41	49.09	204.0
1000-10	5236	52.36	49.04	201.7
1000-10	5250	52.50	49.28	204.5
1000-10	5229	52.29	48.97	200.0
1000-10	5192	51.92	48.60	196.0
1000-10	5107	51.07	47.75	181.0
1000-10	5042	50.42	47.10	174.3
1000-10	5000	50.00	46.68	177.2
1000-10	4927	49.27	45.95	168.6
1000-10	4830	48.30	44.98	158.0

Curve of Change of Resistance with Temperature of Top Coil.

Abscissae - Degrees Fahrinheit as marked.
Ordinates - Ohms resistance as marked.



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1000-10	4700	47.00	43.68	145.7
1000-10	4625	46.25	42.93	138.0
1000-10	4550	45.50	42.18	129.3
1000-10	4500	45.00	41.68	124.0
1000-10	4400	44.00	40.68	113.4
1000-10	4358	43.58	40.28	108.0
1000-10	4250	42.50	39.18	97.0
1000-10	4223	42.23	38.91	95.2
1000-10	4210	42.10	38.78	94.1
1000-10	4150	41.50	38.18	88.3

The entire iron wire was calibrated or $\frac{732}{46354}$ more than was within the cylinder. The increase in resistance was therefore $\frac{732}{46354}$ more than under conditions of test. The corrected resistances (measured resistance less leads) were plotted in accompanying curve.

The temperature corresponding to 46.354 ω in cylinder is the

temprature corresponding to
$\frac{47086}{46354} \times 46.354$ on curve since the
resistance of calibrated for the
respective temperatures was in-
creased in the ratio of $\frac{46354+732}{46354}$
The temprature is 181° fahr.

The temprature of the waste
gases at the top of the fire-box
was found by means of change
in resistance of same coil that
was used for finding the temper-
ature at the bottom of cylender
and contained the same amount
of wire as was calibrated.

Used Queen Bridge Box # 39 and
Willyoung d'Arsonval galvanom-
eter to measure change of resist-
ance. The following is the
result of the measurements
of resistance :—

The leads measured .135 ω.

Ratio of arms	Ohms from box	Resistance	Resistance less leads.
1000 - 10	4270	42.70	42.54
1000 - 10	4250	42.50	42.34
1000 - 10	4290	42.90	42.74
1000 - 10	4320	43.20	43.04
1000 - 10	4330	43.30	43.14
1000 - 10	4330	43.30	43.14
1000 - 10	4336	43.36	43.20
1000 - 10	4340	43.40	43.14

giving a mean resistance of 42.91 ω this substituted in equation for temperature gives 1008° Fahr. as temperature at top of air-box.

On the measurement of both the high temperatures the coil was again measured after cooling down. Its resistance was found to be the same as before

rest showing that wire was not oxidized by heat materially.

The following preliminary tests and calibrations of the apparatus used were made.

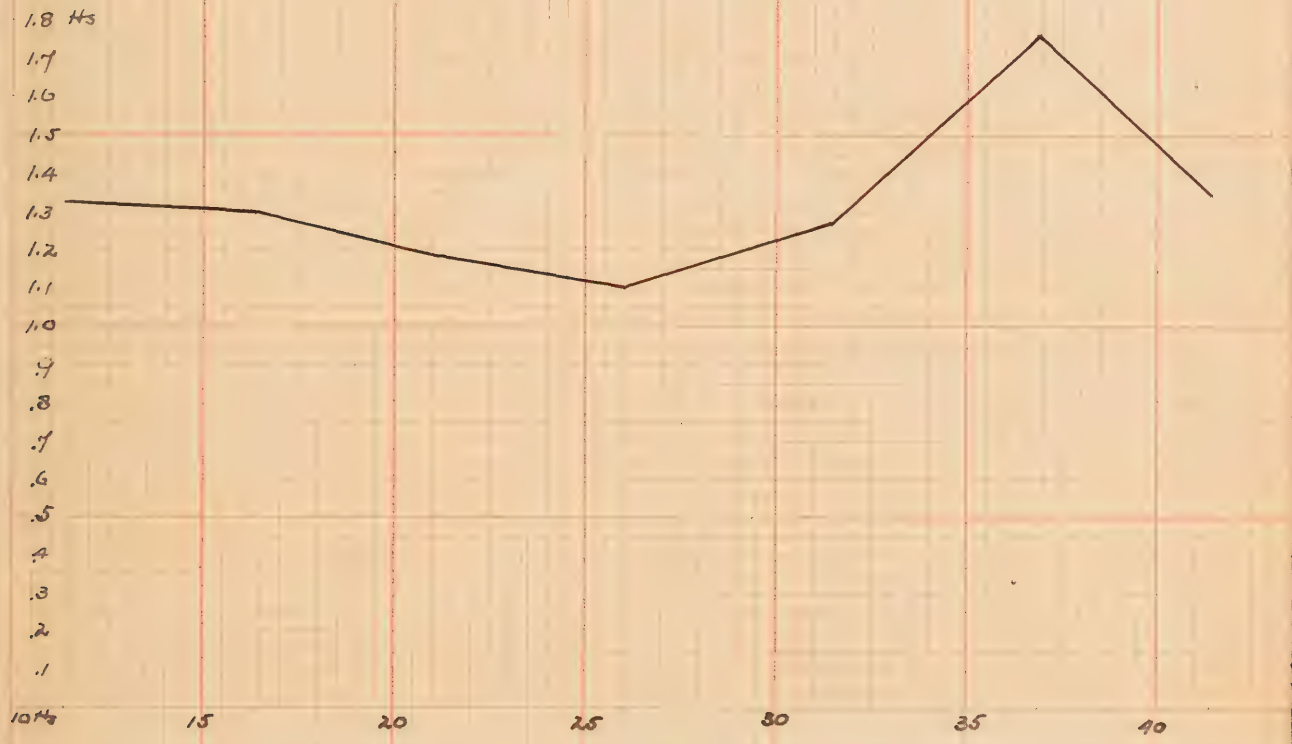
Bourdon Gauge #21001 used to measure pressure pumped against. Calibrated on Crosby Gauge Tester.

on tester.	Before runs Gauge Up	Down	Mean	After runs Gauge Up	Down	Mean	Mean of two
5	6.5	6.8	6.65	6.25	6.75	6.50	6.57
10	11.1	11.2	11.15	11.00	12.00	11.50	11.32
15	16.1	16.1	16.10	16.25	16.75	16.50	16.30
20	21.1	21.1	21.10	20.75	21.75	21.25	21.17
25	26.9	26.5	26.70	25.50	25.50	25.50	26.10
30	31.1	31.8	31.40	31.00	31.50	31.25	31.32
35	36.8	36.8	36.80	36.50	36.75	36.62	36.70
40	41.5	41.4	41.45	41.50	42.00	41.75	41.55

From the mean of the two

Calibration Curve of Bourdon Gauge #210018.

Abscissae – Actual readings on gauge
Ordinates – tobe subtracted from actual readings
togive true readings.



calibrations the accompanying curve was drawn and pressures of run corrected by interpolation.

The Bristol Recording Gauge used to measure the gas pressure was directly calibrated by means of U tube and columns of water. A special scale was drawn from the direct calibration.

Calibration of 10# Spring of Straight Line Indicator #511. Tested above atmospheric pressure with Crosby Gauge Tester.

On tester.	Up		Down	
	Height on cards	Spring Scale	Height on cards	Spring Scale.
5	.43"	11.63	.48	10.42.
6	.54"	11.11	.58	10.34
7	.63"	11.11	.68	10.29

Below the atmosphere the spring was calibrated by connecting indicator to a U tube with

mercury columns, and exhausting the air by means of a Bunsen Bell connected to the water faucet as shown

Inches mercury	Equivalent pounds	Height on card.	Spring scale.
1	.489	.05	9.78
1 1/8	.586	.06	9.77
1 1/2	.733	.08	9.16
2 1/2	1.22	.12	10.17
5 1/4	2.56	.22	11.67
5 1/2	2.68	.27	9.96
5 1/2	2.68	.24	11.17
7	3.42	.34	10.06
7 1/2	3.66	.33	11.09
7 1/2	3.66	.34	10.78
8	3.91	.37	10.03
4 1/2	2.20	.18	12.22
8 1/4	4.03	.40	10.07
8 1/4	4.03	.39	10.33
8 5/8	4.22	.38	11.10
8 5/8	4.22	.41	12.93

In the first run the card was sixty above the atmospheric pressure line; a mean of the eight readings between 0.0 and 2.65 lbs. was taken which gave for scale 10.49; and a mean of six readings of five, six and seven pounds on rotor giving scale of 10.82. The two combined give for ring scale = 10.61

For second run, in which the pressure was more nearly balanced above and below the atmospheric line, a mean of the above six-readings below the atmosphere was taken (10.64); and a mean of the four readings for five and six pounds above (10.87). The mean of the two gives 0.75 for the scale of the spring for the second run.

Before the test was the pump packing was tightened up so no leakage occured, but the engine had been run so much as to make it impossible to tighten up the piston packing without putting in a new leather. The air therefore leaked in so much as to make the indicator card mostly above the atmospheric line. The machine was oiled thoroughly about every quarter hour.

Apparatus Used.

Bourdin Gauge # 210015

Bristol Recording Gauge.

Queen Torricellian Barometer, reading to 1/500".

Two Queen Fahr. Thermometers divided very 2° up to 400°.

Straight Line Indicator # 511 with 10 # spring.

	Time	Card No.	Area card	Length card	Mean length	Micrometer counter Start	Finish	Rev. min.	Temp.	Corrected micrometer	Height of tool	Effective head	Weight Left tank	Weight Right tank	Diff.	Rev. min.	Temp.	Rev.	Mean	Remarks
	11.30	12	1.62	3.94	.411	4420	4481	61	24	22.87	2'8"	56.02	412		184	88	89	4.38	29.770	
	.35	13	1.65	3.93	.397	4730	4793	63	22	20.84	2'5"	51.05		950	195	89	88	4.38		
	.40	14	1.61	3.98	.405	5046	5107	61	23	21.85	2'11"	52.19		504	154	88	89	4.34	29.760	
	.45	15	1.64	3.97	.413	5354	5416	62	23	21.85	2'2"	53.15		680	176	90	90	4.30		
	.50	16	1.61	4.00	.403	5664	5725	61	23	21.85	2'8"	53.64	408		180	90	89	4.28	29.760	
	.55	17	1.60	4.00	.400	5977	6044	67	22	20.84	2'6"	51.13	575		167	90	89	4.30		
	12.00	18	1.55	4.06	.382	6305	6369	64	21.5	20.33	2'11"	50.35	754		174	90	90	4.30	29.750	
	.05	19	1.65	3.95	.418	6632	6697	66	22.5	21.35	2'5"	52.21		333	177	91	90	4.34		
	.10	20	1.64	4.02	.408	6965	7032	67	22.5	21.35	2'2"	51.96		508	175	91	90	4.38	29.750	
	.15	21	1.70	4.00	.425	7295	7361	66	22.5	21.35	3'0"	52.79		685	177	91	89	4.38		
	.20	22	1.65	3.99	.414	7623	7689	66	23	21.85	2'8"	53.64	412		184	92	90	4.36	29.750	
	.25	23	1.66	3.97	.418	7951	8016	65	23	21.85	2'6"	53.43	585		173	92	90	4.33		
	.30	24	1.77	3.96	.447	8311	8376	65	23	21.85	3'1"	54.06	760		175	92	90	4.34	29.750	
	.35	25	1.66	3.97	.418	8606	8673	67	24	22.87	2'2"	55.53		336	181	92	92	4.33		
	.40	26	1.74	4.03	.432	8937	9002	65	24	22.87	2'5"	55.78		511	175	92	92	4.40	29.750	
	.45	27	1.67	3.97	.421	9265	9330	65	24	22.87	2'9"	56.11		685	174	91.5	92	4.40		
	.50	28	1.66	3.98	.417	9600	9668	68	22.5	21.35	2'5"	52.21	416		188	92	93	4.40	29.750	
	.55	29	1.62	3.96	.409	9940	8	68	22.5	21.35	2'8"	52.45	600		184	92	93	4.38		
	1.00	30	1.67	3.96	.422	279	346	67	22	20.84	2'8"	51.29	776		176	92.5	91	4.38	29.750	
	.05	31	1.67	4.00	.418	614	681	67	22	20.84	2'4"	50.96		337	182	92	92	4.40		
	.10	32	1.68	3.97	.423	947	1012	65	23	21.85	2'2"	53.15		515	178	91.5	92	4.42	29.750	
	.15	33	1.68	3.96	.424	1305	1369	64	23.5	22.36	2'7"	54.75		689	174	90	92	4.40		
	.20	34	1.70	3.94	.432	1596	1661	65	23	21.85	2'4"	53.31	408		180	91.5	94	4.40	29.750	
	.25	35	1.69	3.96	.427	1923	1989	66	24	22.87	2'0"	55.36	581		173	92	94	4.38		
	.30	36	1.65	4.00	.413	2275	2281	66	20.5	19.31	2'9"	47.81	770		189	92	91	4.38	29.760	
	.35	37	1.68	3.95	.425	2639	2709	70	20	18.79	2'11"	46.75		345	190	92.5	91	4.40		
	.40	38	1.65	4.00	.413	2978	3048	70	20	18.79	2'5"	46.26		530	185	92.5	93	4.38	29.750	
	.45	39	1.66	4.00	.415	3327	3397	70	20.5	19.31	2'11"	47.97		715	185	92.5	94	4.38		
	.50	40	1.72	4.00	.430	3676	3746	70	21	19.82	2'5"	48.67	420		192	92	94	4.40	29.750	
	.55	41	1.66	3.94	.421	4033	4103	70	21	19.82	2'7"	48.83	615		195	92.5	94	4.38		
	2.00	42	1.63	3.94	.414	4390	4460	70	21	19.82	3'1"	49.33	817		202	92.5	90	4.40	29.750	
	.05	43	1.62	4.00	.405	4743	4812	69	21	19.82	2'3"	48.50		342	184	93	98	4.40		
	.10	44	1.67	4.00	.418	5087	5156	69	20.5	19.31	2'1"	47.23		527	185	94	96	4.40	29.750	
	.15	45	1.68	4.00	.420	5423	5490	67	20	18.79	2'11"	46.75		705	173	93.5	96	4.32		
	.20	46	1.69	3.95	.415	5758	5826	68	20.5	19.31	2'4"	47.64	413		185	94	96	4.36	29.730	
	.25	47	1.69	3.97	.426	6098	6167	69	22	20.84	2'3"	50.38	600		187	94.5	96	4.40		
	.30	48	1.74	3.99	.436	6440	6509	66	22	20.84	2'11"	51.54	778		178	95	94	4.40	29.730	
	.35	49	1.72	3.96	.434	6775	6844	69	22	20.84	1'11"	50.54		337	179	95	96	4.38		
	.40	50	1.69	3.96	.424	7105	7177	69	21.5	20.33	2'2"	49.61		514	176	96	96	4.33	29.730	
	.45	51	1.68	3.97	.423	7442	7509	67	22	20.84	2'11"	51.54		691	177	95	97	4.30		
	.50	52	1.71	3.94	.430	7707	7775	66	21.5	20.33	2'2"	49.61	411		178	95	96	4.30	29.730	
	.55	53	1.68	3.96	.424	8102	8169	67	22	20.84	2'6"	51.13	590		179	96	94	4.40		
	3.00	54	1.65	4.00	.413	8438	8505	67	22.5	21.35	2'11"	52.76	730		190	96	93	4.40	29.760	
	.05	55	1.68	4.00	.420	8775	8843	68	21	19.82	1'10"	48.07		345	190	96	94	4.36		
	.10	56	1.66	4.00	.415	9114	9181	67	20.5	19.31	2'0"	47.06		530	185	96.5	95	4.36	29.770	
	.15	57	1.67	4.00	.418	9451	9519	68	21	19.82	2'10"	49.03		708	178	96	95	4.38		
	.20	58	1.67	4.00	.418	9787	9865	67	21.5	20.33	2'7"	52.12	415		187	97	95	4.36	29.770	
	.25	59	1.59	4.00	.398	135	202	67	21.5	20.33	2'6"	52.04	600		135	97	95	4.35		
	.30	60	1.64	4.03	.407	472	539	67	21.5	20.33	2'10"	52.37	790		190	97	95	4.38	29.770	
	Total				20.466			3275				2571.31			8903	4547	4541	214.18	743.790	
	Mean				.418			66.90				52.48				92.8	92.8	4.39	29.752	

American Meter Co's 5 light Meter
#903951.
Ashcroft Revolution Counter.
Two Fairbank's Platform Scales.

The data of run on accompanying table.

Reading meter start 11.30 - 555
" " end 3.30 - 747
or 195 cu. ft. of gas burned in run of 4 hrs. or 48 3/4 cu. ft. per hour.

The result of analysis of products of combustion made in Elliot Apparatus during run was as follows:-

Time	Orig Vol.	After KOH	% CO_2	After pyro.	% O	After Cu_2Cl_2	% CO
2.30	100.0	91.2	8.8	87.6	3.6	87.2	.4

The percentages of O and CO show that about the proper amount of O was supplied to burners and perfect combustion secured. No odor from the burners was noticeable.

The following are results of four analyses of city gas, made in the chemical laboratory on different days :-

					Mean.
CO_2	0.0	0.0	0.0	0.4	0.10
Heavy hydrocarbons	4.0	4.6	4.80	4.6	4.50
O	2.2	1.0	2.20	2.8	2.05
CO	6.0	7.2	7.20	6.2	6.65
CH_4	30.4	34.7	31.80	29.24	31.54
H	53.2	50.3	51.01	50.51	51.25
N	4.2	2.2	2.99	6.25	3.91
	100.0	100.0	100.00	100.00	100.00

In working out the heat value of the gas burned used heat equivalents, weight of gases, etc, as given in "Winkler and Lunge's Technical Gas Analysis."

Since the composition of the

gas varied so little from time to time, assumed that in both runs it had the above mean composition.

Data:- 195 cu. ft. gas

Mean barometer = 29.752" mercury

" pres. of gas = 4.39" water

" temp. of gas = 92.8° Fahr.

Gas saturated with water vapor.

29.752" = 755.7008 mm.

4.39" water = $\frac{4.39}{13.596}$ x 25.4 mm. of mercury = 8.199

∴ Total pressure = 763.8998 mm. of Hg.

92.8° Fahr. = 33.8° Cent.

The value of the aqueous tension as given in tables for 34° = 39.5 mm.

763.90 - 39.5 = 724.40 mm. = pres. of gas at 34°.

at 0° Cent., 760 mm. pressure it was found from tables that 195 cu. ft. would give

195 x .8477 = 165.3 cu. ft. = 4681.4 litres under normal conditions.

From Tables :-

Substance.	Kilogrammes per litre.		French calories per kilogramme.	
CH_4	.0007154		13346	
H	.0000896		34180	
CO	.0012512		2442	
Heavy Hydro Ethylene C_2H_4	.0012517	.001247	12444	12200
Heavy Hydro Ethane C_2H_6	.0012413		11957	

1 French calorie = 3.968 B.T.U.

4681.4 x .3154 x .0007154 x 13346 x 3.968 = 55941 B.T.U. in CH_4

4681.4 x .5125 x .0000896 x 34180 x 3.968 = 2956 B.T.U. in H.

4681.4 x .0665 x .0012512 x 2442 x 3.968 = 3862 B.T.U. in CO

4681.4 x .045 x .001247 x 12200 x 3.968 = 12717 B.T.U. in Heavy H.

The above gives a total of 101676 B.T.U. consumed in 4 hours.

The diameter of pump plunger = 1 19/32" or area = 2.011 sq. in. Stroke of pump = 8 5/16" This gives a volume of 16.717 cu. in. swept through per stroke. Number of strokes in four hours = 16128 16128 x 16.717 = 269622 cu. in.

8903 lbs water pumped = 246150 cu. in.

269622 - 246150 = 23472 cu. in. slip.

$\frac{23472}{269622} = 11\%$

Mean height of card first - .41

Spring scale - 10.61

Mean revolutions per min. - 67.2

Area piston - $3.1416 \times 4^2 = 50.26$ sq. in.

Stroke - 4" - .333 ft.

$I.H. = \frac{418 \times 10.61 \times 50.26 \times .333 \times 67.2}{33000} = .15$

Total amount of water pumped in four hours - 8903 pounds

Mean head pumped against - 52.48 ft.

$\text{Effective } H. = \frac{8903 \times 52.48}{60 \times 4 \times 33000} = .057$

Total heat units expended in first run = 101676 B.T.U.

Value of same in ft. lbs. = $101676 \times 778 = 79103928$

Total useful work - $8903 \times 52.48 = 467219$ ft. lbs.

The Commercial efficiency of engine and pump = $\frac{467229}{79103928} = .0059$

The Mechanical efficiency of the combination = $\frac{\text{Effective HP}}{\text{I.H.P.}} = \frac{.059}{.151} = .39$

The Carnot efficiency = The difference of temperatures in cylinder, over the higher temperature = $\frac{1577 - 642}{1577} = .59$

The amount of heat used in the cylinder per stroke was calculated in the following ways:-

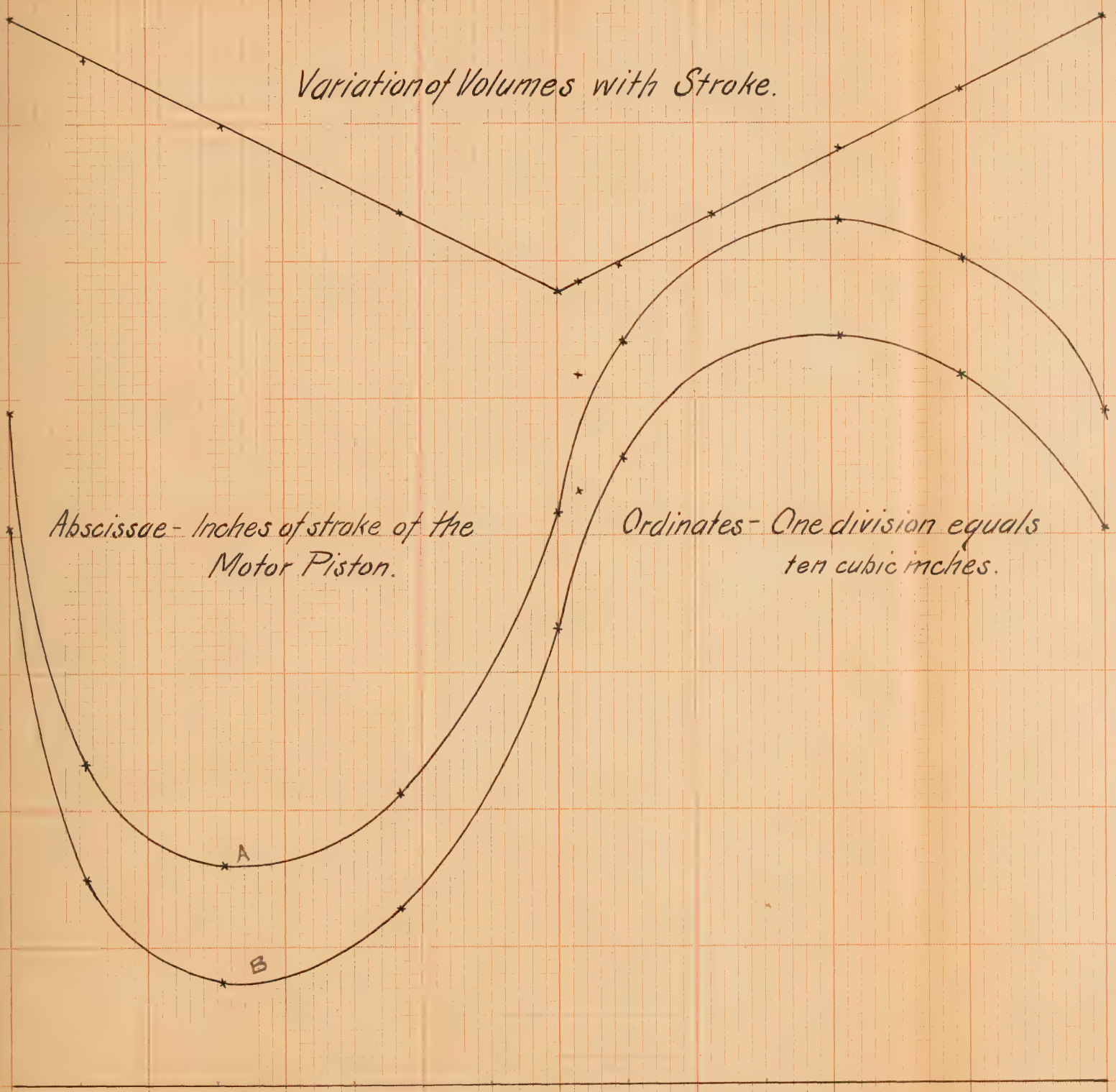
four cards were selected at random from each run and a mean card for each test drawn. Each card was divided into ten parts and the height of card above and below the atmospheric line measured on the mean ordinate of each of these

parts. The mean of the four values was plotted to give the accompanying mean indicator card.

The ordinates measured showing the variations in the cards are given below. (A) signifies above the atmospheric line and (B) below.

Card 21.		Card 31.		Card 41.		Card 50.		Mean Card.	
.60 (A)	.36 (A)	.60 (A)	.36 (A)	.60 (A)	.38 (A)	.61 (A)	.34 (A)	.60 (A)	.37 (A)
.60 (A)	.20 (A)	.60 (A)	.20 (A)	60 (A)	.22 (A)	.61 (A)	.22 (A)	.60 (A)	.21 (A)
.58 (A)	.04 (A)	.60 (A)	.06 (A)	.60 (A)	.05 (A)	.61 (A)	.09 (A)	.60 (A)	.06 (A)
.53 (A)	.06 (B)	.57 (A)	.03 (B)	.60 (A)	.04 (B)	.59 (A)	.04 (B)	.57 (A)	.04 (B)
.50 (A)	.13 (B)	.51 (A)	.10 (B)	.50 (A)	.11 (B)	.55 (A)	.10 (B)	.51 (A)	.11 (B)
.42 (A)	.14 (B)	.45 (A)	.12 (B)	.44 (A)	.14 (B)	.46 (A)	.12 (B)	.44 (A)	.13 (B)
.33 (A)	.15 (B)	.38 (A)	.12 (B)	.37 (A)	.13 (B)	.38 (A)	.13 (B)	.36 (A)	.13 (B)
.24 (A)	.15 (B)	.29 (A)	.12 (B)	.27 (A)	.13 (B)	.30 (A)	.14 (B)	.28 (A)	.13 (B)
.13 (A)	.15 (B)	.20 (A)	.12 (B)	.16 (A)	.12 (B)	.18 (A)	.14 (B)	.17 (A)	.13 (B)
.01 (A)	.14 (B)	.05 (A)	.05 (B)	.03 (A)	.03 (B)	.03 (A)	.03 (B)	.03 (A)	.06 (B)

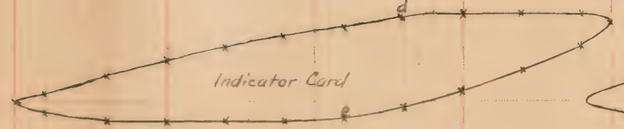
The volumes of the air in the cylinder were measured and the

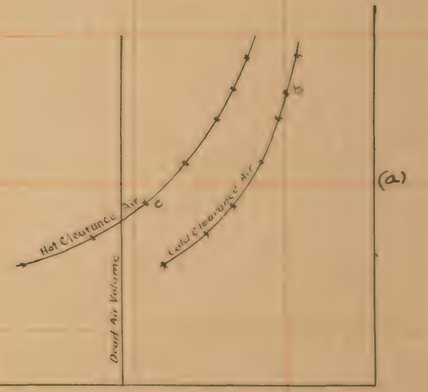

Variation of Volumes with Stroke.
Abscissae - Inches of stroke of the Motor Piston.
Ordinates - One division equals ten cubic inches.
A
B

curve of "Variation of Volumes with Stroke" plotted. The upper straight line represents total volume at different points of stroke, the volume being measured from the lower horizontal base line. The volume of cold air (at 181°) above the transfer piston is laid down from the total volume line to give the curve (A). The ordinates between (A) and (B) represent the constant dead air volume (that around the transfer piston at a constantly changing temperature). The ordinates below (B) to the base line represent the volumes of hot air (at 1116°).

The maximum total volume in cylinder was laid off from the furthest point of indicator card to give the zero volume line (a).

Indicator, Working Air, Clearance and Dead Volume Cards of First Run.





Abscissae - One division equals five cubic inches.
Ordinates - One division equals 1.061 pounds per square inch.

The volumes of the cold and hot air clearance volumes were taken from the least volumes of the cold and hot air on the volume curve. The corresponding position of the motor piston was found on the indicator card and the corresponding pressures for the volumes. The clearance volumes, so measured, were laid off from the zero line on the pressure found giving the points (b) and (c). These clearance volumes remaining at the same temperature, an isothermal was drawn through them. The dead air volume was laid off also. From the total volume within the cylinder represented by points on the indicator card, the sum of the clearance and dead air

volumes was subtracted to give points on the working air card.

At the point of maximum hot air volume on the volume curve the corresponding pressure and volume on the working air curve was taken and from this the weight of working air was calculated from the formula, $W = \frac{pV}{RT}$

The heat was obtained by measuring the area under the top line of working air card and to this adding $W C_v (T_1' - T_2')$

The volume for first mm card - .571 cu. in.

" pressure " " " " - 19.63 lbs.

" temperature " " " " 1577 °Abs.

Wt. of working air $= \frac{19.63 \times 144 \times .571}{53.37 \times 1577 \times 1728} = .01007$ lbs.

The area under top line to base of

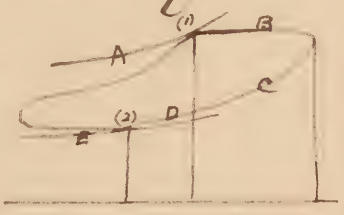
no pressure = 6.07 sq. in. at = 268.3 ft. lbs.

$WC_v(T_1 - T_2) = .0100 \times 130(1577 - 642) = 1224$

1224 + 268 = 1492 ft. lbs. heat added per stroke.

The amount of heat was worked out directly from the mean indicator card in another manner.

In any cycle, the energy at end, plus the work done, minus the heat added, equals the energy at the beginning. The energy at any point equals $\frac{pV}{41}$ where p is pressure in pounds per square foot, and V is the volume of gas in cubic feet.



From the above expression the energy at the highest point of pV of card, say at (1) and at the lowest (2) is known. The heat added is therefore A + B - C - D - E.

The point (d) on the indicator card of first run corresponded to the greatest energy in the air ($\frac{pV}{.41}$ = 2697 ft. lbs.) while (c) that of the least energy ($\frac{pV}{.41}$ = 1761 ft. lbs.) The area beyond (d) below the upper line equalled 2.75 sq. in. or 121.6 ft. lbs. The area beneath the lower line to (c) equalled 2.70 sq. in. 119.4 ft. lbs.

The average heat per stroke of first run was therefore 2697 + 122 - 1761 - 119 = 939 ft. lbs.

The above results obtained in the two different ways do not agree very well although in second run they do much more nearly. The latter should be more nearly correct since it makes no assumptions as to the character of lines, volumes, temperatures, etc.

Accordingly the results obtained in the latter way were adopted.

Work of average card = 76.0 ft. lbs.

Average heat of card = 939 ft. lbs.

The Thermodynamic efficiency = $\frac{76}{939}$ = .081

The Thermodynamic efficiency seems apparently to be very low. The following assumptions are interesting showing in a measure how the heat is used.

The Carnot efficiency was 59%, or if the engine was a perfect one working under the most favorable conditions, of the heat put in .59 only could have been gotten out in work.

Assuming the engine had a perfect regenerator, then the heat given along the constant pressure line would have been eliminated. Assuming the changing pressure

line under the above conditions, to be an isothermal, which it closely approximates, then the heat given the air would have been the work under this line. This area is 3.52 sq. in. or the heat equals for the first run, 155.6 ft. lbs. The work of the card is 76.0 ft. lbs. The Kennedy engine efficiency under these favorable conditions would be 48.9 % which is quite comparable with the Carnot efficiency, and shows how much a regenerator would improve the efficiency of the engine.

Assuming the heat added per stroke to be equal to the work beneath the entire upper line, the following efficiency was obtained. The area under the upper line was found to represent 268.3 ft. lbs.

Sample Card of Second Run. Card #12.

University of Pennsylvania.

DEPARTMENT OF MECHANICAL ENGINEERING.

Card No..... Date,..... 189..... Taken by.....

Which Engine,..... Which End,..... SCALE,.....

BOILER PRESSURE,..... VACUUM, ins.,..... REVOLUTIONS,..... Feed,.....

Inj. Water,..... Discharge,..... Condensed Steam,..... Engine Room,.....

Piston Diameter,..... Stroke..... Piston Rod,..... Barometer ins.,.....

Engine Constant,..... *Diagram Area,*..... *Length,*.....

M. E. P. Head,..... *Crank,*..... *I. H. P. Head,*..... *Crank,*..... *TOTAL,*.....

Remarks:

This gives for the Thermodynamic efficiency $\frac{76.0}{268.3} = 28\%$, also very low. The greater part of the heat actually used in the engine is given along the constant pressure line.

The total amount of heat in ft. lbs. used within the cylinder during the first run = 16128 x 939 = 15144192. ft. lbs.

Total heat furnished by gas = 79103928 ft. lbs.

Efficiency of Air = $\frac{15144192}{79103928} = .19$

Ratio of Thermodynamic to Carnot Efficiency = $\frac{.081}{.59} = .14$

Second Run.

Before the second run the piston and pump were repacked but run sufficiently to take out the stiffness. The pump leaked consider-

Time	Card No.	Area Card.	Length	Mean height	Revolution counter. Start	Finish	Rev. per min.	Pressure on gauge.	Corrected Pressure.	Height from lower tank.	Effective head.	Weights Left tank.	water pumped Right tank.	Diff.	Temp. outflow	Temp gas.	Gas pressure	Barometer.
10.05	3	2.12	4.00	.530	5115	5156	41	36	34.3	1'5"	80.63		280	125	77	93	4.15	
.10	4	2.18	4.00	.545	5328	5373	45	32	32.5	2'0"	77.06		400	120	78	86	4.15	29.994
.15	5	2.23	4.00	.557	5540	5579	39	31.5	30.3	1'11"	84.59		500	100	80	87	4.15	
.20	6	2.04	4.00	.510	5777	5829	42	28	27.8	2'3"	68.74		615	115	79	87	4.15	29.992
.25	7	2.04	3.98	.512	6040	6093	53	29	27.8	2'9"	66.95		730	115	80	88	4.20	
30	8	2.01	4.03	.499	6327	6379	52	34	32.8	2'8"	69.18	395		167	79	84	4.20	29.994
.35	9	2.02	4.00	.505	6588	6609	51	29.5	27.3	2'4"	67.93	510		115	80	83	4.20	
.40	10	2.06	4.05	.504	6812	6863	51	32	30.6	2'3"	72.42	645		135	80.5	84	4.20	29.974
.45	11	2.11	4.12	.512	7068	7119	51	33	31.6	2'5"	75.39	778		133	80	84	4.20	
.50	12	2.11	4.05	.521	7318	7364	46	32	30.6	2'4"	73.08		288	133	81	78	4.24	30.006
.55	13	2.14	4.03	.531	7554	7607	50	34.5	32.9	2'1"	78.32		408	120	81	76	4.24	
11.00	14	2.19	4.10	.534	7801	7849	48	34.5	32.9	2'3"	78.07		535	127	82	84	4.22	30.012
.05	15	2.11	4.00	.528	8044	8092	48	35.5	33.9	2'1"	80.54		650	115	82	80	4.20	
.10	16	2.15	4.10	.524	8288	8337	49	31	29.7	1'11"	70.67	367		139	82.5	72	4.24	30.014
.15	17	2.11	4.04	.522	8532	8581	49	35	33.4	2'4"	79.05	493		126	82.	71	4.24	
.20	18	2.09	4.00	.523	8772	8821	49	33	31.6	2'3"	75.31	610		117	82.5	76	4.28	30.000
.25	19	2.09	4.00	.523	9010	9057	47	33.5	32.0	2'1"	75.15	725		115	83	70	4.28	
.30	20	2.06	4.03	.511	9241	9288	47	32	30.6	2'4"	72.75		285	130	83	70	4.24	30.000
.35	21	2.11	4.00	.528	9475	9523	48	36	34.3	2'5"	81.55		400	115	83	72	4.20	
.40	22	2.08	4.08	.510	9723	9771	48	37	36.3	2'5"	86.25		510	110	83.5	74	4.24	30.010
.45	23	2.04	4.05	.504	9937	9985	48	37	35.3	2'3"	83.77		630	120	83.5	70	4.24	
.50	24	2.09	4.00	.523	10169	10211	42	34.5	32.9	2'2"	78.16	354		126	83	74	4.28	30.018
.55	25	2.18	4.02	.542	10331	10423	42	36.5	34.7	2'4"	82.70	457		103	83.5	76	4.38	
12.00	26	2.19	3.98	.550	10592	10638	46	39	37.3	2'5"	88.55	564		107	84	76	4.20	30.015
.05	27	2.10	4.08	.515	10838	10884	49	35	33.4	2'0"	79.14	700		136	84.25	78	4.24	
.10	28	2.13	4.00	.533	11075	11123	48	35	33.4	2'0"	79.14	800		100	84.25	77	4.20	30.015
.15	29	2.10	4.00	.525	11302	11350	48	37.5	35.7	2'7"	85.26		272	117	84.5	76	4.24	
.20	30	2.16	4.05	.533	11536	11585	49	40	38.4	2'3"	90.93		385	113	84.5	76	4.28	30.010
.25	31	2.08	4.00	.520	11795	11844	49	36.5	34.7	1'11"	82.28		505	110	85	76	4.30	
.30	32	2.01	4.00	.503	12024	12072	48	34	32.5	2'3"	77.31		622	117	85.5	79	4.30	30.015
.35	33	2.07	3.97	.521	12310	12355	48	36.5	34.7	2'5"	82.78	356		128	85.	80	4.32	
.40	34	2.08	3.96	.525	12498	12545	47	33	31.6	2'2"	75.15	470		114	85.5	79	4.34	30.010
.45	35	2.13	4.00	.533	12751	12798	47	35	33.4	2'10"	79.97	589		119	86	79	4.30	
.50	36	2.09	4.00	.523	12962	13009	47	37	35.3	2'3"	83.77	703		114	86	79	4.30	30.030
.55	37	2.12	4.00	.530	13197	13243	46	38	36.3	2'11"	86.75	814		111	85.5	79	4.40	
1.00	38	2.13	3.98	.535	13426	13473	47	37	35.3	2'1"	83.60		270	115	86	79	4.40	30.040
.05	39	2.24	3.96	.566	13631	13672	41	36	34.3	1'6"	80.72		370	100	87	77	4.40	
.10	40	2.23	3.97	.562	13837	13880	42	37	36.3	2'2"	86.01		473	103	87.5	79	4.42	30.030
.15	41	2.19	4.00	.548	14045	14093	45	37	35.3	2'8"	84.18		590	97	88	76	4.50	
.20	42	2.22	3.98	.558	14262	14310	42	39.5	37.8	2'10"	90.13		679	119	88.5	78	4.50	30.030
.25	43	2.25	4.00	.563	14484	14526	42	39	37.3	1'7"	87.72	350		128	89	79	4.52	
.30	44	2.25	4.00	.563	14698	14743	45	39	37.3	2'5"	88.55	445		95	89	78	4.54	30.032
.35	45	2.26	4.02	.562	14916	14964	48	39.5	37.8	2'3"	89.55	543		98	89.5	79	4.52	
.40	46	2.28	3.98	.572	15130	15173	43	38	36.3	2'6"	86.34	639		96	89.5	78	4.52	30.030
.45	48	2.29	4.00	.573	15343	15386	43	37.5	35.7	2'4"	85.26	742		103	89.5	80	4.60	
.50	49	2.29	3.96	.589	15561	15605	44	40.5	38.9	1'11"	91.75		262	107	90	79	4.58	30.040
.55	50	2.30	3.94	.584	15779	15822	43	41	39.4	2'5"	93.41		358	96	91	78	4.60	
2.00	51	2.30	3.94	.584	15994	16038	44	41.5	39.9	1'9"	93.90		460	102	91	79	4.58	30.040
.05	52	2.31	3.97	.582	16211	16254	43	42	40.4	2'3"	95.54		565	105	92	79	4.58	
Total				26.246			2270				3886.58			5671	4136.5	3897	211.80	720.360
Mean				.536			46.33				79.38				84.4	79.5	4.32	30.015

ably at the top due to the vibration of the pump rod. The piston was quite tight which made an equal distribution of air possible, as shown by the cards of the second run.

The data of run on accompanying table.

Eighty pounds of water leaked from top of pump during the four hours which was added to the amount pumped.

Same apparatus used in this as on previous test.

Reading meter, 7-35-1090

" " 2-05-1300

or 210 cu. ft. burned in 4½ hours, 46.7 cu. ft. in four hours or 46.7 cu. ft. per h.p. slightly below the amount of former run.

After reducing the quantity of gas burned to normal conditions (0° Cent. and 760 mm.) the heat value of gas was worked out by proportion with former runs, the composition being assumed the same.

Data:- 186.7 cu. ft.

Mean barometer = 30.015"

Mean gas pressure = 4.32"

Mean temp. gas = 79.5° Fahr.

30.015" = 762.381 mm. 79.5° Fahr = 26.4° C.

4.32" water = 8.068 mm. of mercury.

762.381 + 8.068 = 771.449 mm = pressure on gas and water vapor at 26.4° C.

Pressure of aqueous vapor at 26° = 25 mm.

Pressure of gas alone = 771.449 - 25 = 746.45

At 0° Cent. and 760 mm. it was found from tables that 186.7 cu. ft. would occupy 186.7 x .79671 = 167.4 cu. ft = 4741.4 litres.

First run had 4681.4 litres or 101676 B.T.U.

$\therefore \frac{x}{101676} = \frac{4141.4}{4681.4}$ $x = 102,980$ B.T.U. consumed in second run.

Weight of water pumped = 7751 pounds = 159004 cu. in.

Volume swept through by pump plunger per stroke = 16.717 cu. in.

Total number of strokes in four hrs 11119

$16.717 \times 11117 = 185876$ cu. in - total volume swept through.

$185876 - 159004 = 26872$ cu. in slip.

% slip $= \frac{26872}{185876} = .14$

Mean height of card second run = .531"

Spring scale second run = 10.75

Mean revolutions per minute = 46.33

Area piston = 50.26 sq. in.

Stroke = 4"

I.H.P. $= \frac{.536 \times 10.75 \times 50.26 \times .333 \times 46.33}{33000} = .135$

Total amount of water pumped in four hours - 5751 pounds.

Mean head - 79.38 ft.

Effective H.P. $= \frac{5751 \times 79.38}{60 \times 4 \times 33000} = .0576$ H.

Total heat units expended - 102950 B.T.U.

Value of same in ft. lbs. - 80118440 ft. lbs.

Total useful work - $5751 \times 79.38 = 456514$ ft. lbs.

The Commercial Efficiency of engine and pump $= \frac{456514}{80118440} = .0057$

The Mechanical efficiency of combination $= \frac{.0576}{.135} = .427$

The test was obtained in a manner similar to the first one.

Four cards were selected and their ordinates measured. The readings are given in the table below.

Card 13.		Card 22.		Card 32.		Card 40		Mean Card	
.51 (A)	.13 (A)	.60 (A)	.24 (A)	.50 (A)	.14 (A)	.62 (A)	.20 (A)	.56 (A)	.18 (A)
.51 (A)	.06 (B)	.60 (A)	.06 (A)	.50 (A)	.04 (B)	.62 (A)	.05 (A)	.56 (A)	.00
.51 (A)	.20 (B)	.60 (A)	.06 (B)	.50 (A)	.14 (B)	.62 (A)	.09 (B)	.56 (A)	.12 (B)
.50 (A)	.27 (B)	.56 (A)	.15 (B)	.49 (A)	.26 (B)	.58 (A)	.20 (B)	.53 (A)	.22 (B)
.38 (A)	.35 (B)	.47 (A)	.23 (B)	.37 (A)	.34 (B)	.50 (A)	.28 (B)	.48 (A)	.30 (B)
.29 (A)	.35 (B)	.40 (A)	.28 (B)	.30 (A)	.36 (B)	.40 (A)	.30 (B)	.35 (A)	.32 (B)
.20 (A)	.36 (B)	.30 (A)	.29 (B)	.20 (A)	.37 (B)	.30 (A)	.31 (B)	.25 (A)	.33 (B)
.10 (A)	.37 (B)	.20 (A)	.27 (B)	.10 (A)	.36 (B)	.14 (A)	.31 (B)	.15 (A)	.33 (B)
.01 (A)	.36 (B)	.10 (A)	.27 (B)	.02 (A)	.35 (B)	.10 (A)	.31 (B)	.06 (A)	.32 (B)
.10 (B)	.30 (B)	.00	.20 (B)	.10 (A)	.30 (B)	.00	.28 (B)	.05 (A)	.27 (B)

Average volume of working air for second run = 522. cu. in.

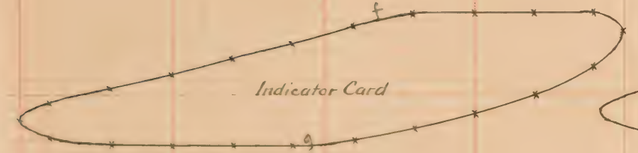
Pressure = 18.92 lbs.

Temperature - 1577° Fahr.

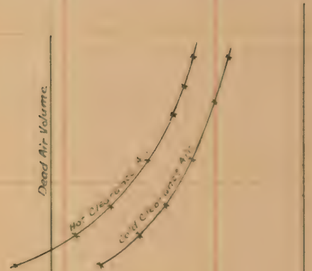
Wt. of working air = $\frac{18.92 \times 144 \times 522.}{53.37 \times 1577 \times 1728} = .00978$ lbs.

The area under top line to line of no pressure - 5.75 sq. in = 235.2 ft. lbs.

Indicator, Working Air, Clearance and Dead Volume Cards of Second Run.



Abscissae - One division equals five cubic inches.
Ordinates - One division equals 1.075 pounds per square inch.



$WC_v(T_1 - T_2) = .00978 \times 130(1577 - 642) = 1189$ ft. lbs.

1189 + 235 - 1424 ft. lbs. heat used in cylinder per stroke.

By the other method the following result was obtained:-

Point (f) gave the greatest energy (2700 ft. lbs) in the air in cylinder for second one. The point of least energy occured at (g) and the air there contained 1508 ft. lbs. of energy. The area of the card beyond (f) equalled 3.17 sq. in. or represented 142.0 ft. lbs. The area below the lower line was 2.54 sq. in. or 115.1 ft. lbs.

The heat per stroke - 2750 + 142 - 1508 - 115 = 1229 ft. lbs.

This more nearly agrees with the other method.

The average work per card 96.8 ft. lbs.

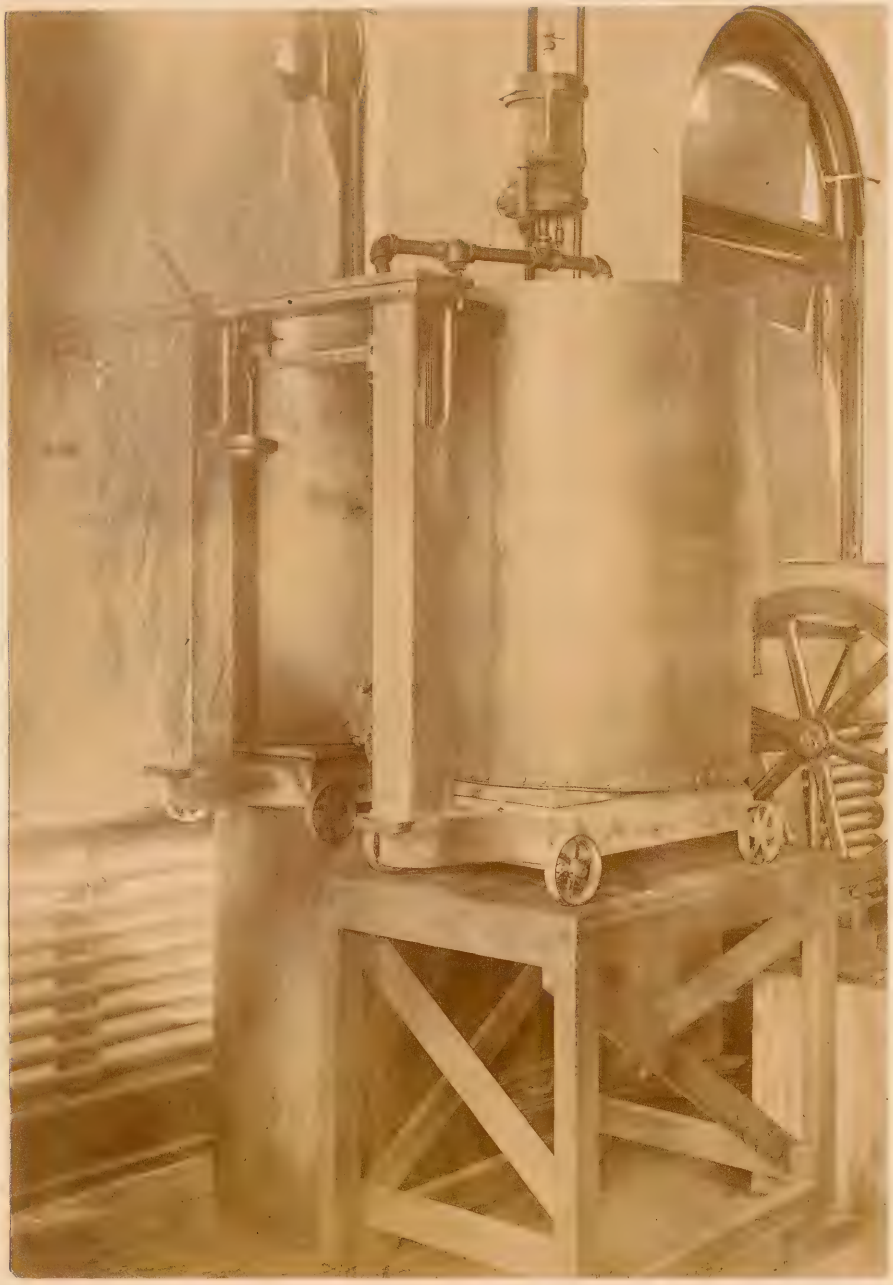
Thermodynamic efficiency $\frac{96.8}{1229} = .079$

Ratio of Thermodynamic to Carnot efficiency - $\frac{.079}{.59} = .134$

Total amount of heat used within the cylinder during the run - 1119 x 1224 - 1366251

Total heat furnished by gas - 80118440 ft. lbs.

Efficiency of fire - $\frac{1366251}{80118440} = .17$



3 1198 03072 7916
N/1198/03072/7916X

3 1198 03072 7916
N/1198/03072/7916X